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Design and construction of a simple blade pitch measurement system for small wind turbines

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1. Introduction

Reliability in performance is a key factor in ensuring the sustainable operation of a small wind turbine. Despite the great potential of small wind turbines to provide electric power, particularly in remote areas, many small wind turbines have short lifetimes due to technical failures or the excessive costs of numerous maintenance visits [1]. In developing countries where the support infrastructure for wind turbine operation and maintenance has yet to be established, turbine reliability has a higher priority than efficiency of the turbine or, to quote from Schl  pfer [2], “10% efficiency of something is always better than 80% efficiency of nothing”.

For wind turbines to be reliable they must have in place good mechanisms to protect themselves against very high winds or sudden removal of load. Both these scenarios can lead to “over-speeding” of the turbine rotor where the rotor experiences speed excursions that exceed the rated speed of the blade manufacturer. Over-speeding can lead to blade collapse with the possibility of damage to other turbine components and people and structures in the vicinity [3, 4]. For small horizontal-axis wind turbines (typically in the size range 0.1 – 30 kW [5]), passive or mechanical protection systems are often used. One common protection method is that of blade feathering [6, 7] where the turbine reacts to very high rotor speeds by reducing the pitch of its blades, thus regulating rotor speed by reducing the aerodynamic torque on the rotor.

Turbine reliability not only relies on using protection methods like blade feathering but it is vital that the blade pitching mechanism is tested before the turbine is installed in the field. The Research Institute of Sustainable Energy (RISE) has an Outdoor Test Area specifically designed for the field testing of renewable energy technologies [8]. Researchers at the Outdoor Test Area have 10 years of experience in testing small wind turbines and have played a key role in the demonstration of small wind turbine technology in remote areas such as Exmouth in Western Australia and the Cocos Islands [9, 10].

Measuring the degree of blade pitching produced by a blade pitching mechanism on a small wind turbine involves a number of challenges including the fact that all or part of the measurement equipment would need to be located on the rotating hub or rotor of the wind turbine. Mahmud, Dutton and Infield [11] report on an optical slip-ring telemetry system designed to transfer pitching moment and teeter data from the rotary frame of reference of a 16kW turbine. In general, however, manufacturers of small wind turbines cannot afford this level of detailed turbine instrumentation and rigorous testing.

The aim of this work was to develop a simple blade pitch measurement system (BPMS) that could be used to measure the changes in blade pitch produced on a small wind turbine by a blade pitching protection mechanism. The specific objectives of the work were to build a BPMS that was inexpensive and uncomplicated in design that would provide enough resolution to give a small wind turbine manufacturer clear feedback about the performance of the turbine’s blade pitching mechanism. The methodology was to design, construct and bench test the BPMS and then install the system on a small wind turbine at the RISE Outdoor Test Area in order to conduct some field testing.

2. Design Process and Construction

The design philosophy in developing the BPMS involved using low power draw items on the hub and a ground-based data logger to avoid the expense and inconvenience of repeatedly

lowering and raising the turbine. Table 1 shows the components that were sourced to construct the BPMS.

Component	Description	Proposed Location	Cost Estimate (\$AUD)
Sensor	Absolute Contacting Encoder (8-bit gray code output)	Hub	20
Transmitter	916MHz RF module	Hub	125
Transmitter Power Supply	8 x 1.5V batteries	Hub	25
Transmitter Antenna	3" whip antenna of solid stranded wire	Hub	–
Receiver	916MHz RF module	Ground	125
Receiver Power Supply	1 x 7Ah battery	Ground	75
Receiver Antenna	6-element Yagi	Ground/Tower	120
Miscellaneous	Brackets, mounting board, cabinet, cabling etc.	Hub & Ground	200
TOTAL			690

Table 1. Components used in the construction of the BPMS

The BPMS uses a hub-based absolute contacting position encoder to measure the blade pitch angle and a telemetry system consisting of a pair of wireless RF modules to convey this information to the ground-based logger. It was envisaged that the telemetry transmitter would be powered by a string of batteries on the hub of the turbine while the telemetry receiver would be powered by a single 7Ah battery. Note that the power arrangements for the telemetry system during bench testing of the BPMS varied from this design (see Section 3).

An estimate is given of the total cost of the BPMS as \$690 AUD, considerably less than the thousands or tens of thousands of dollars that can be spent on more complex pitch measurement systems and thus attractive to a small wind turbine manufacturer. Note that this price is solely for the components that make up the BPMS and excludes that of a data logger, which is assumed to be already in situ in order to record turbine power output. Since the absolute contacting position encoder outputs 8 bit gray code it is also assumed that the existing logger is capable of sampling digital bytes.

3. Bench Testing

The BPMS components were assembled for bench testing. The transmitter was powered with a 9V battery and the receiver was powered from the mains supply. Three inch whip antennas were used for both RF modules. Rotating the shaft of the contacting encoder through 360 degrees generated 128 unique Gray codes at the output of the terminals of the encoder. The terminals of the encoder were connected to the inputs of the transmitter, which scanned its inputs 16 times per second and transmitted the state of each input to the receiver. The receiver outputs were connected to a group of 8 digital channels on a dataTaker® DT800 data logger.

A logging program was developed that simulated the installation of the BPMS on a wind turbine. The design philosophy of the software program was to capture detailed information when conditions of interest arose such as changes in pitch angle or evidence of over-speeding. The structure of the program was such that detection of conditions of interest triggered a dynamic logging schedule which would scan the group of digital inputs on the logger, interpreting the 8-bit Gray code as a pitch displacement of the blades from the rotor plane. This pitch angle was then logged, together with other relevant data, such as the wind speed and rotor speed.

4. Field Testing the BPMS

4.1. The RISE Outdoor Test Area

Field trials of the BPMS were undertaken using Westwind turbines at the RISE Outdoor Test Area. Monitoring campaigns were undertaken with the BPMS firstly installed on a 20kW Westwind turbine on a 30m guyed tower at Wind Test Station #1 of the Outdoor Test Area [8]. The BPMS was then installed on a 30kW Westwind turbine, which replaced the 20kW wind turbine at Test Station #1.

The 20kW and 30kW turbines both use a pitch weight over-speed protection mechanism (PWOPM) to achieve blade feathering. As the rotor spins, the pitch weights are thrown outward under centrifugal forces and the blades rotate about the radial pivot bearing. The arms of the pitch weights are connected to restraint springs to govern the rotor speed at which feathering occurs. The tension of the restraint springs can be adjusted by changing the point of connection of the springs to the pitch weight arms or changing the location of springs with respect to the pivot bearing.

The wind turbines at Test Station #1 were monitored for power performance using a dataTaker® DT800 data logger. Wind speed and direction data were sampled and correlated with turbine power data using guidelines provided by the wind turbine power performance testing standard, IEC61400-12 [12]. Data were stored on a memory card that was periodically removed from the logger to transfer the logged data to a PC for validation and analysis.

4.2 Installing the BPMS on small wind turbines

The BPMS was incorporated into the existing monitoring system described in Section 4.1. Figure 1 shows the installation of the BPMS on the 20kW Westwind turbine at the RISE Outdoor Test Area. Firstly the encoder was installed in the radial pivot bearing and the shaft of the encoder was attached to a reference arm by means of small flexible coupling. Secondly the transmitter was installed on a circular wooden board and inserted into the nose cone of the turbine. On the back of this board was a string of batteries that powered the transmitter and were arranged to be radially equidistant from the axis of rotation so as to not cause imbalance. Finally the encoder outputs were connected to the transmitter inputs by shielded cable.

During the installation phase, there was some experimentation with the type and placement of the antennas. The final arrangement used a 3" whip antenna in the nose cone for the transmitter and a Yagi antenna for the receiver. In some campaigns the Yagi antenna was placed at the base of the tower, while in others it was mounted on a wind sensor boom on the wind turbine tower at 24m height.

The receiver outputs were connected to a group of 8 digital channel inputs on the DT800 data logger. The software schedules developed during bench testing were incorporated into the logging program of the existing monitoring system and the program parameters were modified to suit the characteristics of the turbine and of the site.



Figure 1 Installing the BPMS on a Westwind 20kW wind turbine (adapted from Stevens [13])

4.3. Results from Over-speed Testing.

Over-speed tests were conducted by waiting until the turbine was well-loaded and then suddenly unloading the turbine by manually tripping the main circuit breakers between the wind turbine and the turbine controller and load. Sudden removal of generator load from the turbine imparts a reaction torque on the rotor and induces speed up.

Figure 2 shows data collected from the dynamic logging schedule during over-speed testing of the 20kW Westwind turbine. The figure clearly shows fluctuations in pitch angle which correspond to fluctuations in rotor speed. This suggests that the largest pitch deployment occurs for the greatest values of rotor acceleration. A review of all data collected during this campaign suggests that for a sudden increase in rotor speed, pitch deployment lags rotor speed by a period of a few seconds, whereas for a sudden decrease in rotor speed pitch deployment lags rotor speed by a period of 15-20 seconds. Figure 3 shows data captured during over-speed testing of the 30kW turbine. The lag between pitch angle and rotor speed is again noticeable but the time lag in redeployment has considerably reduced compared to the 20kW results. This is discussed further in Section 5.

All dynamic pitch angle data from the over-speed tests of the 20kW turbine on June 27 2006 and from the over-speed tests of the 30kW turbine on October 3 2006 were binned with respect to rotor speed (Figure 4). Both the binned curves from the 20kW and 30kW turbine data show marked increases in pitch angle with rotor speed followed by a curve plateau. The results for the 20kW and 30kW machines indicate that the pitch mechanism is deploying at rotor speeds significantly below that of the blade manufacturers rated wind speed of 240 rpm. In the case of the 20kW turbine data, the blades have pitched around 6 degrees even before the turbine has reached its cut-in rotor speed of 80 rpm. The other notable point from Figure 4 is that the 20kW and 30kW turbines reach speeds of 200 rpm and above, yet the PWOPM has only deployed over half of its full range. In viewing Figure 4, the Reader has to keep in mind that the last few points of the curve are not statistically significant and more data would have to be collected to confirm this behaviour.

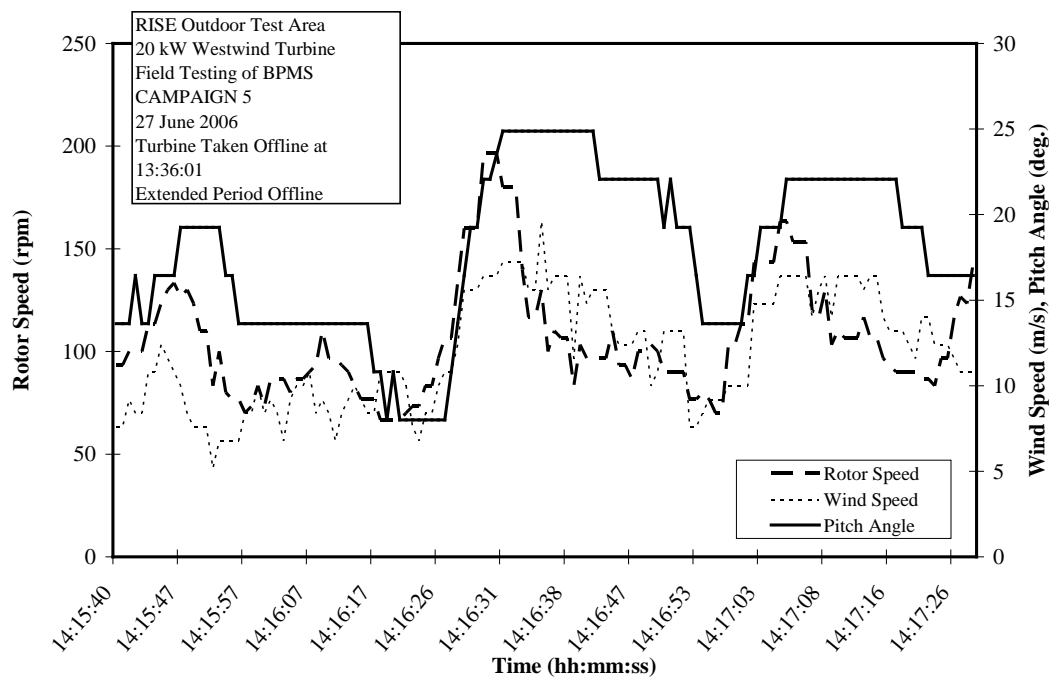


Figure 2 Data captured during over-speed testing of the 20kW turbine on June 27 2006

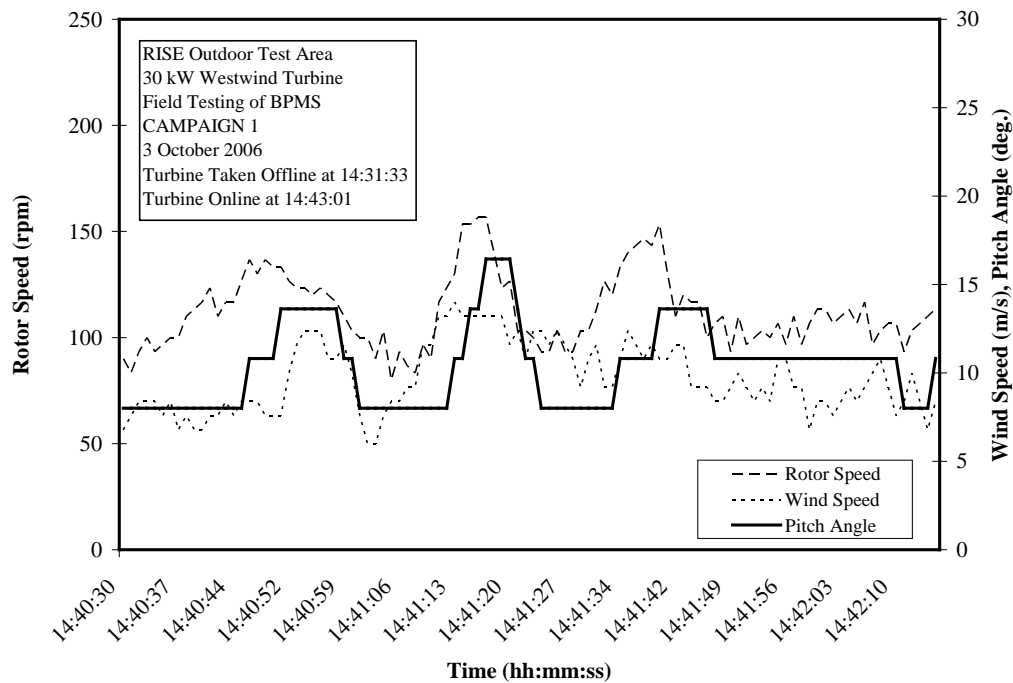


Figure 3 Data captured during over-speed testing of the 30kW turbine on October 3 2006

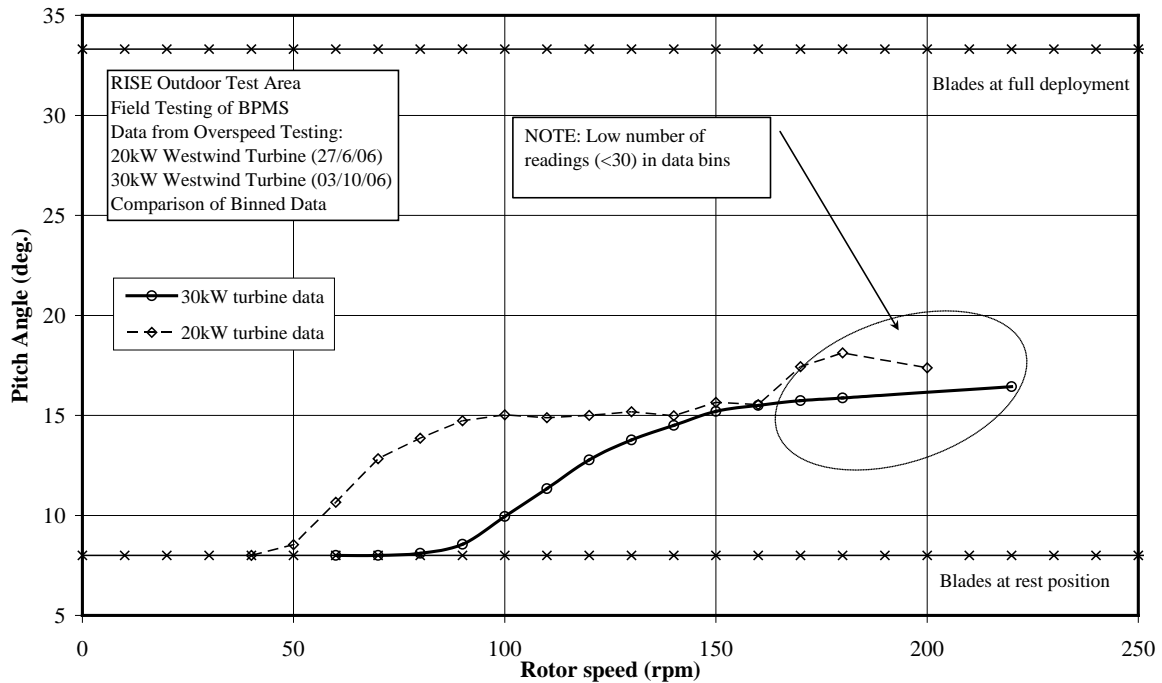


Figure 4 Binned pitch angle data with respect to rotor speed for both the 20kW and 30kW wind turbines

5. Discussion

The lag between changes in rotor speed and changes in pitch angle displayed in Figure 2 indicated the possibility that the pitch weights were being hampered in their redeployment and this was communicated to the turbine manufacturer, Westwind. During the changeover from the 20kW to the 30kW turbine Westwind engineers observed that the thrust washer on the blade bearing had rusted on the 20kW machine and this was replaced by a Teflon-coated thrust washer for the 30kW machine. In addition longer slots were cut into the nose cone for the 30kW machine for ease of passage of the springs of the PWOPM. The results of Figure 3 suggest that the Teflon coated thrust washer and longer slots in nose cone have had a positive effect on the smooth passage of the pitch weights.

The deployment of the PWOPM at low rotor speeds for the 20kW machine as shown in Figure 4 was communicated to Westwind in order that they could increase the spring tension to prevent this early deployment. The initial results from the 30kW suggest this problem has been improved (in the sense that the blade do not deploy until after cut-in rotor speed) but it is still likely that the deployment of the PWOPM occurs too early resulting in reduced performance of the turbine. Figure 4 also indicated that the PWOPM for the 20kW was not making use of its full range of deployment. This was also communicated to Westwind although initial results from the 30kW turbine show that this has still not been resolved.

The success of the BPMS has to be weighed against its limitations. The main limitations include the resolution of the absolute contacting encoder, delays in the telemetry system, variations in signal strength and the effect of centrifugal forces on the batteries in the nose cone. At the time of writing this paper, none of these limitations are considered to be serious.

6. Conclusions

A blade pitch measurement system (BPMS) has been developed and has proved to be a simple and cost-effective means of logging blade pitching on small wind turbines. Most importantly, the

BPMS provides enough resolution to give the small wind turbine manufacturer clear feedback about the performance of their blade pitching protection mechanisms.

The BPMS has been tested in the field on a 20kW and a 30kW Westwind turbine, both of which use a pitch weight over-speed protection mechanism (PWOPM). The BPMS has revealed a number of issues including:

- (i) problems with smooth redeployment of the pitch weights of the 20kW machine, and
- (ii) early and part-range deployment of pitch weights that affect the output power of the turbines.

This feedback was very important to the manufacturer who acted by using a Teflon-coated thrust washer for the pivot bearing to improve smooth passage of the pitch weights, and by reducing the spring tension of the PWOPM to encourage greater pitch weight deployment.

The results of this paper show that further reductions in spring tension are required. From a small wind turbine manufacturer's point of view the fact the pitch weights are deploying early means that the turbine will be reliable rather than efficient but that they are on the right side of the reliability/efficiency issue i.e. they can work towards improved efficiency by starting off with a reliable turbine.

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